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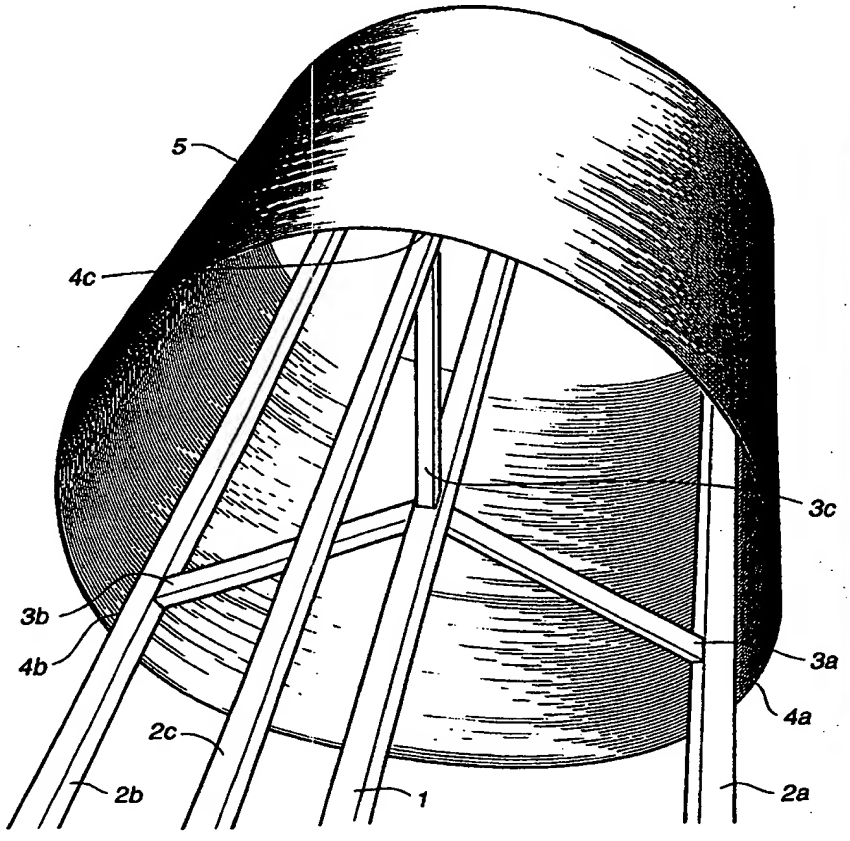
(54) Title: ANODE, PROCESS FOR ANODIZING, ANODIZED WIRE AND ELECTRIC DEVICE COMPRISING SUCH ANODIZED WIRE

(57) Abstract

An anode for batch anodizing of a conductor wire of metal (5). The anode comprises, in addition to the wire, a holder with three or more guide cams (4a, 4b, 4c) to support and hold the wire in the desired position during the anodizing process. The guide cams are arranged with guide slots in which the spirally wound wire is fixed so as to obtain a space between the turns of the wire of the spirally wound conductor wire. The wire is connected at both ends to the positive pole of a current source and the holder and the wire are immersed into an electrolyte during the anodizing.



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Anode, process for anodizing, anodized wire and electric device comprising such anodized wire

TECHNICAL FIELD

The invention relates to an anode for batch anodizing of a length of metallic conductor wire. More specifically, the invention relates to an anode for generating an electrically insulating oxide layer on the surface of a wire length of electric conductor wire of metal by anodizing, wherein the anode is immersed into an electrolyte. The invention also relates to a process for batch anodizing of a wire length of metallic conductor wire, in which such an anode is utilized, an insulated conductor wire with an electrically insulating surface layer generated by batch anodizing according to the invented anodizing process, and an electric device comprising one or more such insulated conductor wires which have been provided with an electrically insulating surface layer by batch anodizing.

BACKGROUND ART

An electric device such as a cable, a transformer, a generator, a motor, etc., comprises at least one current-carrying and voltage-carrying metallic body, hereinafter in this application referred to as a conductor. Certain high-voltage electric devices include conductors which comprise a large number of conductor wires of a more slender dimension, referred to in this application as strands. The strands are composed, for example laid, into parts of strands, windings or coils in generators and other electric machines. The voltage difference between the laid strands is low but the laid strands are still often insulated relative to one another.

According to the prior art, single-wire conductor wires which, as strands, are laid into coarser conductors, included in high-voltage devices, are insulated preferably

by organic insulating materials, such as thermoplastic resins, waxes or varnishes. However, organic insulating materials have a poor capacity to withstand influence in severe environments. For example, they have a low temperature resistance and they must often be applied in relatively thick layers. The organic insulations also give rise to drawbacks and costs when recycling/recovering consumed or rejected conductor material since they have to be taken care of or destructed separately from the metallic conductor wire. For use in severe environments such as at high temperatures, under vacuum, in chemically aggressive environments or in environments involving a high fire hazard, it is known to use inorganic insulating materials such as insulating materials based on glass fibre or mica, which are usually wound onto the conductor wire. Further, it is known to insulate aluminium wire or aluminium-coated copper wire with a surface layer of aluminium oxide by anodic oxidation, anodizing. To obtain an oxide layer with a suitable structure and adhesion for the use described above, a treatment cycle is required which cannot be realized by means of a continuous electrochemical process but requires a batch process. A problem in this connection is to arrange a wire of a wire length sufficient for a coil in an electric high-voltage device. The wire length in a coil usually amounts to between a few two hundred metres and a few kilometres. The wire must in its entirety be connected to the positive pole of a current source in such a way that the potential difference is minimized over the long wire length. The wire, which preferably has a diameter of 1 to 5 mm, must usually be supported and kept in such a way that essentially the whole surface may be anodized.

It is an object of the invention to suggest an anode which comprises a holder suitable for anodizing, in one batch, a conductor wire with a wire length of 100 metres to 10 kilometres.

It is also an object of the invention to suggest an anodizing process for batch anodizing of a conductor wire, an anodized conductor wire manufactured by means of this process, as well as an electric device comprising one or more such anodized wires.

SUMMARY OF THE INVENTION

The above is achieved by means of an anode which is adapted for batch anodizing of a wire length, comprises the wire to be anodized and a holder for supporting and holding the conductor wire, during the anodizing, in such a way that essentially the whole surface of the conductor wire can be anodized, whereby, according to the invention, the wire is spirally wound onto the holder and the holder comprises at least three guide cams with guide slots in which the spirally wound wire is fixed. Preferably, the guide slots are formed such that the contact surfaces between the holder and the wire are minimized essentially into point contacts. The guide slots of the guide cams hold the spiralled conductor wire such that all the turns are separated by a space. By this space between each turn and by the contact surfaces between holder and wire having been minimized, it is ensured that essentially the whole envelope surface of the conductor wire is anodized and that a homogeneous oxide layer is generated. The wire and the holder are immersed into an electrolyte during the anodizing, and the wire is connected at both its ends to the positive pole of a current source. The wire comprises, at least in an outer layer, aluminium or copper which during the anodizing is oxidized into an oxide layer with good adhesion, a suitable structure and a thickness of less than 15 µm, preferably less than 10 µm. This ensures the workability without the oxide layer being damaged or flaked and a sufficient electrical insulation for the limited potential difference between two strands included in the same winding or coil in a high-voltage electric machine. In certain embodiments, the wire is a solid wire of some of these metals or of an alloy based

on aluminium or copper, and in other embodiments a wire with a core of a first metal or alloy coated with a layer comprising aluminium or copper; the core may, of course, comprise aluminium or copper. That is to say, a core of aluminium may be coated with a copper layer, a core of copper with an aluminium layer or a core of copper or aluminium be coated with an alloy comprising copper and aluminium, respectively, where the content of the coating differs from the content of the core. Preferably, during anodizing of a batch of metal wire, a conductor wire with a wire length of 100 metres to 10 kilometres is wound onto the holder. The invention has proved to be exceedingly suitable for anodizing conductor wire with a diameter of 0.1 to 6 mm, preferably 1 to 5 mm.

The guide cams are preferably made of an electrically conducting material such as aluminium, copper or titanium. Under certain conditions, it is also suitable to connect both holder and wire ends to the positive pole of the current source.

In a preferred embodiment, the holder comprises a central shaft and three bars, oriented parallel to the shaft and fixed to the central shaft by means of radially oriented arms. The bars are arranged with guide slots or with guide cams fixed to the bars.

An anode as described above is preferably suitable for use during a batch anodizing where the electrochemical, thermal or other parameters are varied during the process cycle, or during a batch anodizing which goes on for such a long time that a process where the wire is continuously drawn through the anodizing bath is not suitable.

Depending on the electrochemical conditions prevailing in the electrolytic bath, either the whole holder is made of an electrically conducting material and connected as an anode to the positive pole of the current source, or only the

guide cams fixed to the bars are made of an electrically conducting material and connected as an anode to the positive pole of the current source. In the latter case, the guide cams are electrically insulated from the supporting parts of the holder. The electrolyte may contain other metal ions or anions, which during the oxidation are included in the oxide layer and act in a stabilizing way thereon or improve the adhesion to the underlying metal or in certain cases change the surface properties of the oxidized conductor wire, which surface properties facilitate water rejection, the application of polymer-based surface layers outside oxide layers, etc. The contents of such additives to the electrolyte may be controlled during the anodizing. Alternatively, other electrochemical process parameters, which influence the inclusion of such compounds in the oxide layer, may be controlled.

Through the anode and the batch anodizing, described above, it is possible to anodize conductor wires of copper or aluminium or conductor wires coated with any of these metals, such as aluminium-coated copper wires with an electrically insulating oxide layer, which exhibits an adhesion and structure such that they may be treated and formed into coils or windings in a high-voltage electric machine. The adhesion and the structure ensure that the electrical insulation may be achieved with a thin oxide layer, which makes them suitable to use as strands in coils and windings for electric high-voltage devices. It is particularly advantageous to use the anode and the anodizing process mentioned above for anodizing strands which are coordinated into an electric conductor which is wholly or partially surrounded by a polymer-based insulation and arranged to be included in a winding of a high-voltage electric machine.

A conductor wire according to the invention, as well as a high-voltage electric machine comprising such a conductor wire, has an improved poor capacity of resisting the

influence of severe environments. For example, they have a high temperature resistance and may be applied in relatively thin layers. Nor do they give rise to any drawbacks or costs during recycling/recovery of consumed or rejected conductor material since the insulation may be taken care of and destructed together with the metallic conductor wire.

In the following, the invention will be explained in greater detail and be exemplified by means of a preferred embodiment with reference to the accompanying drawing.

BRIEF DESCRIPTION OF THE DRAWINGS

The anode in the figure comprises a holder in the form of a central shaft 1 and three bars 2, 2a, 2b, 2c, arranged parallel to the shaft and fixed to the central shaft by means of radially oriented arms 3a, 3b, 3c. On the bars 2, 2a, 2b, 2c, guide cams 4, 4a, 4b, 4c are fixed. The guide cams 4, 4a, 4b, 4c are of aluminium and are shown in more detail in Figure 2. The guide cams 4, 4a, 4b, 4c may be electrically insulated from the supporting parts 2, 2a, 2b, 2c, 3a, 3b, 3c of the holder. The wire 5 which is to be anodized is spirally wound onto the holder and each turn is fixed in the guide slots of the guide cams 4a, 4b, 4c. At both ends the wire 5 is electrically connected to the positive pole of a current source (not shown). During anodizing, the whole holder with the wound-on wire 5 is immersed into an electrolyte, an electrolytic bath. In the electrolytic bath, the electrochemical, thermal or other parameters are controlled during the process cycle. In certain cases, the process cycle during the batch anodizing takes such a long time that, even if the process parameters are kept essentially constant during the whole anodizing, a process where the wire is continuously drawn through the anodizing bath is not suitable. Depending on the electrochemical conditions prevailing in the electrolytic bath, either the whole holder is made of an electrically conducting material and connected as an anode to the positive pole

of the current source, or only the guide cams 4a, 4b, 4c, fixed to the bars, are made of an electrically conducting material and connected as an anode to the positive pole of the current source. In the latter case, the guide cams 4a, 4b, 4c are electrically insulated from the supporting parts of the holder. The electrolyte may contain other metal ions or anions, which, during the oxidation, are included in the oxide layer and act in a stabilizing manner thereon, or improve the adhesion to the underlying metal or, in certain cases, change the surface properties of the oxidized conductor wire, which properties facilitate water rejection, the application of polymer-based surface layers outside oxide layers, etc. The contents of such additives to the electrolyte may be controlled during the anodizing. Alternatively, other electrochemical process parameters, which influence the inclusion of such compounds in the oxide layer, may be controlled. By means of an anode according to Figures 1 and 2, the batch anodizing may be carried out and a thin oxide layer, less than 10 µm, with good adhesion to the underlying metal and a suitable structure be generated on conductor wires of copper or aluminium or conductor wires coated with any of these metals such as a aluminium-coated copper wires with an electrically insulating oxide layer. Since the oxide layer exhibits a good adhesion and a suitable structure, the conductor wires may be treated and formed into coils or windings in a high-voltage machine without the electrical insulating capacity being reduced by cracks or flaking. This fact, and the small thickness of the oxide layer, contribute to the conductor wires according to the present invention being very suitable to use as strands in coils and windings for electric high-voltage devices. It is especially advantageous to use the anode and the anodizing process, described in the foregoing, for anodizing strands which are coordinated into an electric conductor which is wholly or partially surrounded by a polymer-based insulation and is adapted to form part of a winding of a high-voltage electric machine. A conductor wire according to the invention, as well as a high-voltage electric machine

comprising such a conductor wire, have an improved poor ability to resist the influence of severe environments. For example, they have a high temperature resistance and may be applied in relatively thin layers. Nor does this give rise to any drawbacks or costs during recycling/recovery of consumed or rejected conductor material since the insulation may be taken care of and be destructed together with the metallic conductor wire

CLAIMS

1. An anode which is adapted for batch anodizing of a length of metallic conductor wire (5) and, in addition to the conductor wire (5) to be anodized, comprises a holder for supporting and holding the wire in the desired position during the anodizing, and means for connecting the anode to the positive pole of a current source used for the anodizing, whereby the anode during the anodizing is immersed into an electrolyte, **characterized** in that wire is spirally wound onto the holder, that the holder comprises at least three guide cams (4a, 4b, 4c), that the guide cams comprise guide slots, that the spirally wound wire is fixed in the guide slots, whereby the guide slots arrange the spiralled conductor wire with a separating space between each turn and that the conductor wire at both ends is connected to the positive pole of the current source.

2. An anode according to claim 1, **characterized** in that the guide slots are formed such that the contact surfaces between the holder and the conductor wire (5) are minimized essentially into point contacts.

3. An anode according to claim 1 or 2, **characterized** in that the holder comprises a central shaft (1) and three bars (2a, 2b, 2c) arranged parallel to the shaft and fixed to the central shaft by means of radially oriented arms (3a, 3b, 3c).

4. An anode according to claim 1, 2 or 3, **characterized** in that the guide cams (4a, 4b, 4c) are made of an electrically conducting material.

5. An anode according to claim 4, **characterized** in that the guide cams (4a, 4b, 4c) are connected to the positive pole of the current source.

6. An anode according to any of the preceding claims, **characterized** in that the wire (5), at least in a surface layer, comprises aluminium.

7. An anode according to any of claims 1 to 6, **characterized** in that the wire (5), at least in a surface layer, comprises copper.

8. An anodizing process for batch anodizing of a metallic conductor wire (5) with a limited wire length, wherein the conductor wire (5) is applied onto a holder, is connected to the positive pole of a current source, and is immersed into an electrolyte where it is retained during the anodizing, **characterized** in that the wire is spirally wound onto a holder which comprises at least three guide cams (4a, 4b, 4c) with guide slots, that the spirally wound wire is fixed by the guide slots in an extended position such that all the turns of the spiralled conductor are spaced apart by a separating space between each turn and that the conductor wire at both ends is connected to the positive pole of the current source.

9. An anodizing process according to claim 8, **characterized** in that one or more process parameters are varied during the anodizing, whereby an oxide layer with good adhesion to the underlying metal, a suitable structure and a thickness less than 15 µm, preferably less than 10 µm, is generated on the surface of the wire.

10. An anodizing process according to claim 9, **characterized** in that one or more electrochemical process parameters, such as the current density, are controlled according to a predetermined cycle during the anodizing.

11. An anodizing process according to claim 9 or 10, **characterized** in that the temperature is varied during the anodizing.

12. An anodized conductor wire (5) comprising an oxide layer obtained by batch anodizing of a wire length of metallic conductor wire, **charact rized** in that the oxide layer is thin and exhibits a structure and an adhesion to the underlying metal which make possible treating the wire and shaping it into a strand in a coil or a winding of an electric machine, and that this thin formable oxide layer is sufficiently electrically insulating to constitute an electrical insulation of a strand included in a winding of a high-voltage electric machine, and that this electrically insulating oxide layer is obtained by batch anodizing of a wire length of conductor wire which has been spirally wound onto a holder comprising at least three guide cams (4a, 4b, 4c) with guide slots, whereby, during the anodizing, all the turns of the spirally wound conductor wire have been kept spaced apart by the guide slots, that the conductor wire and the holder have been immersed into an electrolyte and that the conductor wire at both ends was connected to the positive pole of the current source.

13. An anodized metal wire (5) according to claim 12, **characterized** in that the oxide layer of the wire is less than 15 µm, preferably less than 10 µm.

14. An anodized metal wire (5) according to claim 12 or 13, **characterized** in that the wire comprises aluminium.

15. An anodized metal wire (5) according to claim 12 or 13, **characterized** in that the wire comprises copper.

16. A high-voltage electric device with a winding or a coil comprising a plurality of strands electrically insulated from one another, **characterized** in that the strands comprise a metallic conductor wire which is arranged with a thin electrically insulating oxide layer which exhibits a good adhesion to the metal, and a structure which ensures that the thin oxide layer maintains a sufficient electrical insulation of the strand, whereby the oxide layer has been

obtained by means of a batch anodizing of a wire length of conductor wire which has been spirally wound onto a holder comprising at least three guide cams (4a, 4b, 4c) with guide slots, whereby, during the anodizing, all the turns of the spirally wound conductor wire have been kept spaced apart by the guide slots, that the conductor wire and the holder have been immersed into an electrolyte and that the conductor wire at both ends has been connected to the positive pole of the current source.

17. An electric device according to claim 16, **characterized** in that the thin oxide layer exhibits a thickness less than 15 µm, preferably less than 10 µm.

18. An electric device according to claim 16 or 17, **characterized** in that the conductor wires arranged as strands are adapted to form part of a multi-wire conductor, which is wholly or partially surrounded by a polymer-based insulation and is included in a winding of a high-voltage electric machine.

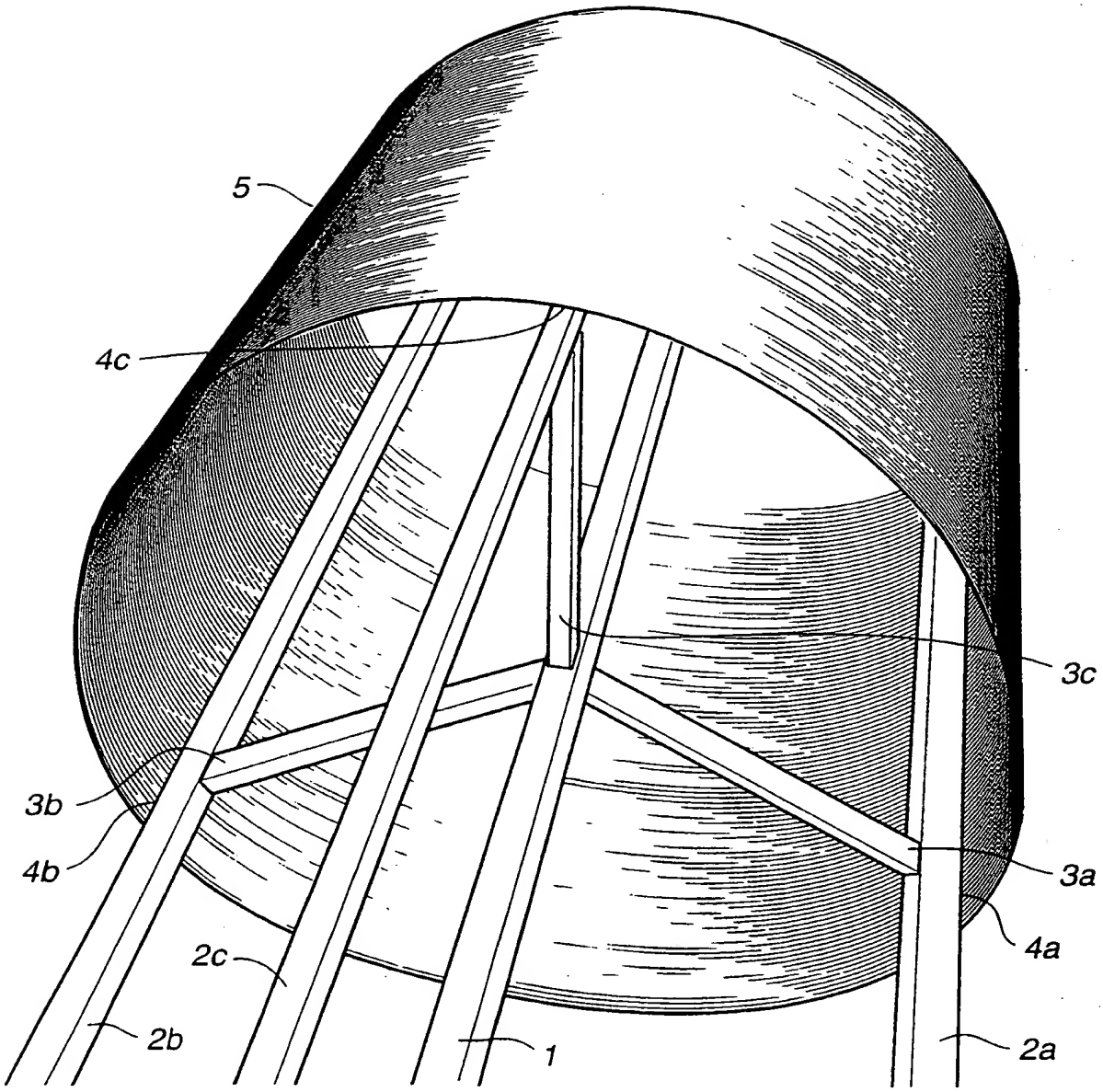

Fig. 1

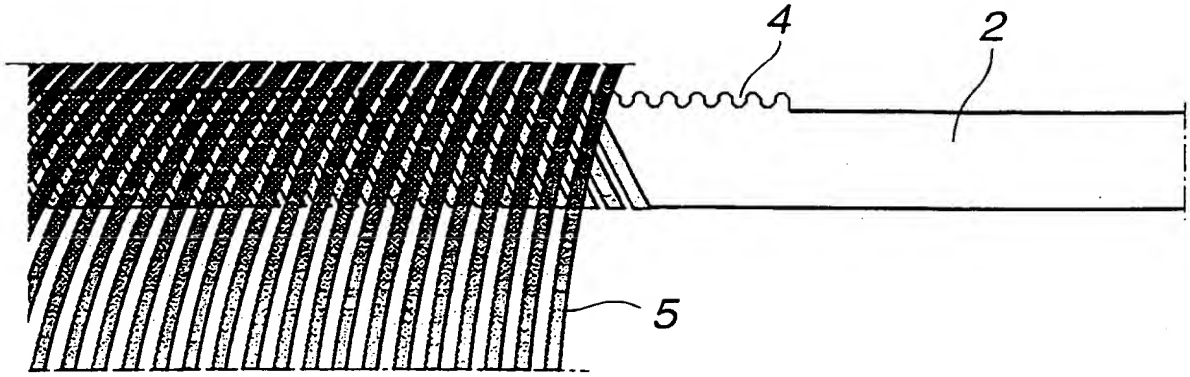

Fig. 2

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 97/01838

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: C25D 11/04, C25D 17/06, H01B 13/16 // H01F 41/12, H02K 15/10
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: C25D, H01B, H01F, H02K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

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C. DOCUMENTS CONSIDERED TO BE RELEVANT

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X	US 4470884 A (DANIEL CARR), 11 Sept 1984 (11.09.84), column 3, line 11 - line 41; column 4, line 44 - line 57, figures 3,6, claims 10,11	1,2,4-18
X	WO 9011389 A1 (MORIOKA MASASHI), 4 October 1990 (04.10.90), figure 1, abstract	1,2,4-18

[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
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PCT/SE 97/01838

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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INTERNATIONAL SEARCH REPORT

Information on patent family members

03/02/98

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